International Compressor Engineering Conference | School of Mechanical Engineering

1994

Initial Development of the Orbital Vane Compressor

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INITIAL DEVELOPMENT OF THE ORBITAL VANE^{tm} COMPRESSOR

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ABSTRACT

This paper reports on the design, development and initial test results of a new type of fluid displacement device known as the Orbital Vane mechanism. This machine contains few and simple parts, all of which consist only of circular and flat shapes. The machine is free of internal rubbing contact and yet provides high volumetric efficiency at low rotor speeds and high discharge pressures. The prototype developmental test compressors deliver energy efficiency and cooling capacity competitive with conventional mobile air conditioning compressors using a variety of refrigerants including HFC-134a. They are quiet and virtually free of vibration and are demonstrating promising reliability.

INTRODUCTION

A relatively large number of different types of compressors have been successfully developed for use in refrigeration, air conditioning, and process gas compression. These compressors include varieties of reciprocating piston machines, conjugate-shaped devices such as scroll, screw, and trochoid compressors, and various configurations of rotary sliding contact vane machines. The fact that many different types of machines have found commercial success in various markets could suggest that: a) there is little room for yet another type of compressor, or, b) there are numerous types of machines because none have proven to possess particularly formidable attributes.

The possibility that the latter may be the case provided the challenge to generate a set of basic compressor engineering design requirements that, if realized, would result in an advanced compressor design. Such a compressor would be easy to produce, offer high levels of economy and reliability, and could be sized and configured to operate over a wide range of capacities and applications.

Although many basic design requirements were considered, eventually only three proved to be fundamental in guiding the design engineering process. These design requirements and their engineering significance are:

Design Requirements:	Design Benefits:
I. Few parts; only flat and round surface shapes	Low cost tooling and manufacturing, high quality
II. No rubbing contact among the moving parts	High efficiency and high reliability
III. Inherently dynamically balanced mechanism	Low vibration and noise

GENERAL DISCUSSION

These foregoing design requirements command the properties of the basic design of an advanced compressor. For example, employing only the easiest shapes to manufacture (single-axis; flat and round) facilitates minimum production costs and optimum quality as well as minimum production system and tooling costs. The elimination of rubbing contact would secure both high energy efficiency and elevated levels of reliability. Further, the absence of rubbing contact provides for wide dimensional scalability by avoiding fundamental materials limitations caused by high velocity rubbing contact. Finally, the absence of dynamic vibration will tend to result in low noise level (and, possibly, an increase in energy efficiency). Low levels of noise and vibration are attributes that are increasingly important in virtually all markets and uses for compressors.

All existing compressors violate at least one of the fundamental design requisites set forth above. For example, scroll, screw, and troichoid machines require the manufacture of complex two- and three-dimensional shapes. Reciprocating and scroll machines are unbalanced mechanisms that demand the use of counterweights. Intense physical rubbing contact occurs between the screws (or drive gears) of screw compressors and between the vane tip and stator wall of rotary vane devices. Thus, the three design constraints set forth here disqualify all compressors currently in commercial existence.

The application of these strict design demands thus required either an entirely new concept in gas compression mechanisms, a major improvement in existing types of compressors, or both. Interestingly, however, of all the commercially-successful compressors, the device that seemed to deviate *least* from the chosen design constraints is the rotary sliding vane compressor. The most common configuration consists only of round and flat shapes, is extremely simple, has large volumetric displacement for its physical size, and is an inherently dynamically balanced device.

The fundamental deficit with sliding vane machines is the severe rubbing contact that occurs between the vane tips and the stator housing wall. However, if an acceptably simple means could be found to eliminate the intense rubbing common to such devices, a new type of positive displacement fluid-handling mechanism would emerge that would satisfy the potent design requirements set forth above.

The search for an advanced compressor eventually narrowed to creating some form of significantly improved non-contact rotary vane device. Interestingly, this design approach reduced the innovative challenge to devising an acceptable vane motion control mechanism. Such a mechanism would have to be elementary enough to maintain the basic simplicity of conventional rotary sliding vane compressors, but provide positive, non-contact sealing at the vane tip.

The vane control mechanism needs to provide only two functions: a) precise circular reference location from the stator (the "radial vane guide"), and b) kinematic coupling of the vanes to this radial position locator (the "vane tether"). This fact indicated that there were only a limited number of means to carry out the goal of providing vane tip clearance precise enough to achieve effective gas sealing.

Specifically, the radial vane guide, since it must have a constant radius, could either be stationary or rotating, thus offering just two fundamental options. A total of five basic means of coupling the vanes to the radial vane guides were found: stub rods, notches, sliders, skates, and rollers. Therefore, the resulting 2 X 5 option matrix confined the total number of alternatives to only ten basic possibilities. Since rubbing friction was disqualified from the outset, only a *rotating* radial vane guide could be considered, thus reducing the number of options to only five.

While a number of means of achieving a non-contact vane mechanism were patented, one method is particularly attractive and was thus chosen for development. In the preferred configuration, the radial vane guide became a simple drawn-cup, anti-friction roller bearing. The kinematic coupler that joins this radial vane guide bearing to the vane was reduced to simple circular bearing segments pinned pivotally to the vane ends. These circular bearing segments can be characterized as individual portions of the inner race of a standard bearing.

DESCRIPTION

The foregoing arrangement is shown in Figures 1 and 2. Figure 1 presents an isometric front and side cut-away of the Orbital Vane^{tm} compressor with labels indicating the primary aspects of the machine and Figure 2 shows a direct frontal view of the machine. As can be seen in the illustrations, the stationary portions of the DynEco Orbital Vane^{tm} Compressor consist of a **Stator** housing with an integral rear endplate and a matching front **Endplate.** Conventional drawn-cup anti-friction roller **Glider Bearings** are pressed into the front and rear internal ends of the compressor. The rotating components consist of a slotted **Rotor** equipped with four radial slots into which fit four identical **Vanes.** The **Vane Gliders** are pinned to the ends of these vanes and are free to rock back and forth on the pins. In turn, these vane gliders fit inside the glider bearings and are thus confined to move in the precision circular path provided by the anti-friction rolling elements of the radial vane guide bearings.

When the rotor is caused to rotate by the **Rotor Shaft,** the rotor slots carrying the vanes impart circumferential motion to each vane. Since the vanes are mechanically coupled to the vane gliders, they are confined to travel in direct conjunction with the precision enveloping circle of the glider bearings. That is, the vanes execute a *circular orbit* within the stator bore that is precisely prescribed by the glider bearings. Therefore, the clearance distance between the tip of the vanes and the cylinder bore of the stator housing can be held to an accuracy limited only by the tolerances met by the simple circular manufacturing processes required to produce the parts. Also, the lubricant contained within the **Lubricant Sump** circulates in the machine and provides for additional gas sealing. Because the rotor center is offset from the center of the stator bore, the rotation of the rotor-vane assembly causes requisite cyclic volumetric changes to occur within the machine: **Inlet,** compression, and **Discharge.**

The achievement of positive-location non-contact vane sealing not only results in high efficiency and inherent machine reliability and longevity, but also yields additional advantages. For example, the absence of rubbing contact enables the use of light rapidly machinable materials such as aluminum or engineered plastics. Furthermore, only minimal surface finishes are needed to build Orbital Vane^{tm} compressors. In addition, this design enables the use of generous and efficient fluid ports because the bore of the stator housing is not required to support the load of the vane tips as is the case with conventional vane compressors.

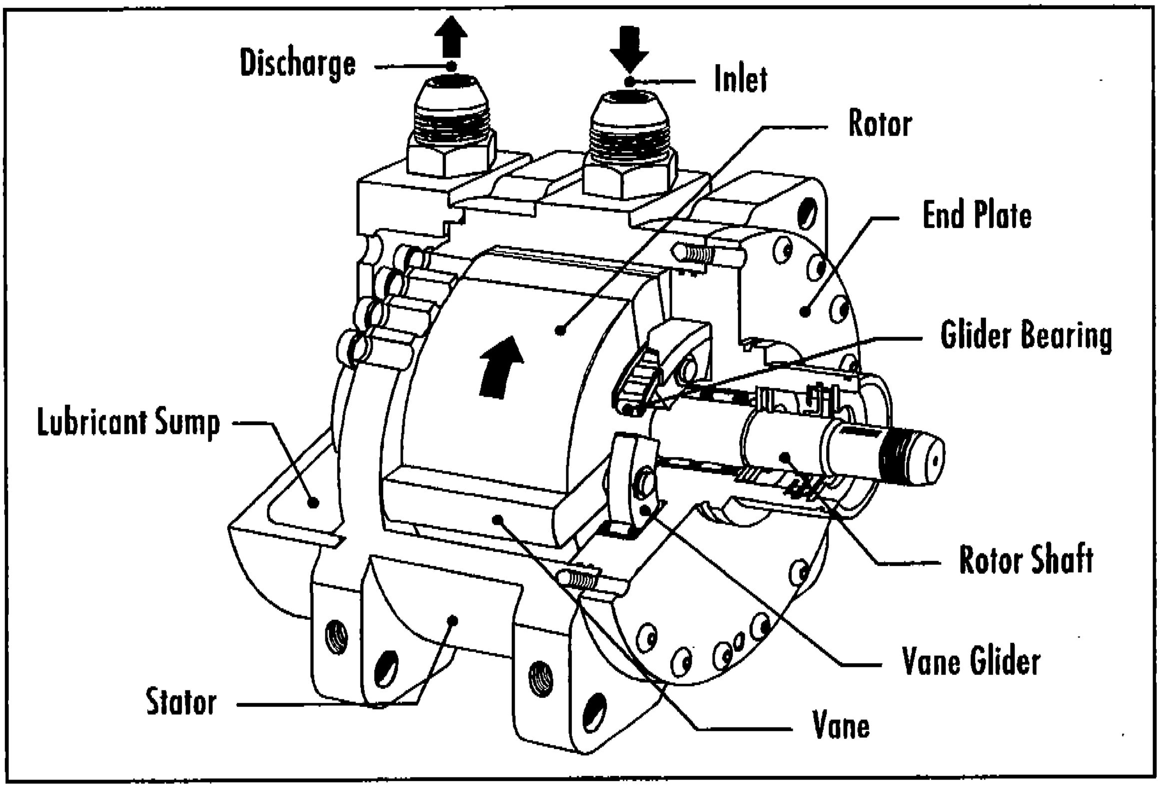

Figure 1: Isometric Sectional View of the Orbital Vane^{tm} Compressor

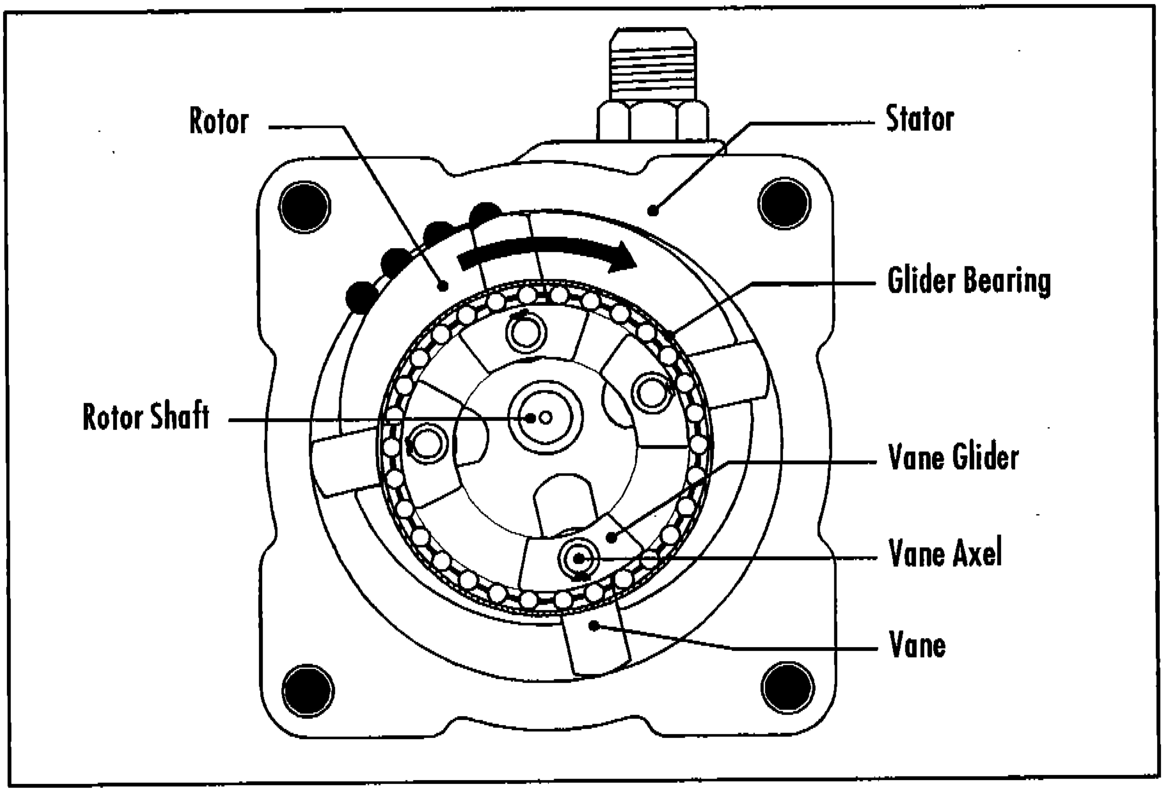

Figure 2: Frontal Phantom View of the Orbital Vane^{tm} Compressor

DEVELOPMENTAL STATUS

At publication, a total of five generations of prototype Orbital Vane^{tm} compressors have been designed, built, and received limited testing. The majority of this engineering development work has been directed toward mobile air conditioning ("MAC") compressors with volumetric displacements on the order of 9 cubic inches (150 cc) per revolution. Further, the majority of these tests has occurred at low compressor speeds because, generally, the most challenging operating conditions for a mobile air conditioning compressor occur at engine-idle speeds. This is the case because the compressor must develop a high level of cooling capacity while running slowly and be capable of doing so at elevated condensing pressure due to minimal ambient air flow over the condenser of a zero or low speed vehicle.

Figure 3 shows a model 409D2 prototype compressor under test in DynEco's air-to-air compressor bench test facility. Figure 4 shows a 409D2 installed in a road test vehicle. Although this 1987 "K"-body vehicle is equipped with CFC-12 components, the road tests are being conducted with HFC-134a refrigerants.

Not being a calorimeter, the compressor test facility was designed primarily to ascertain the comparative effects of developmental design changes on compressor performance and to provide only estimates of absolute performance. However, because direct performance contrasts between competing machines is of primary interest, conventional compressors are occasionally tested "back-to-back". These tests not only provide direct comparative performance data, but also obviate serious departures from meaningful estimates of actual performance.

The compressor test stand consists of a dual-level welded aluminum frame upon which are mounted a solid-state controlled 10 Hp a/c motor compressor drive system. The instruments consist of direct read-out aneroid pressure gages (3% full-scale accuracy), as well as temperature, evaporator air flow velocity, compressor speed and torque read-out equipment. Evaporator air mass flow rate is determined through data generated by a set of traversable dual pitot-static tubes using a direct read-out Magnahelic pressure differential gage (5% full-scale accuracy). Temperatures are determined through the use of type K thermocouples and a switchable multi-input electronic digital temperature read-out (+/- 1F° accuracy). Compressor speed is determined electronically via a magnetic pick-up activated by a 60-tooth ferrous drive gear and displayed by a companion electronic digital RPM display (0.01% accuracy).

Although not yet fully developed, the latest generation developmental automotive Orbital Vane^{tm} air conditioning compressors (Model 409D2) offer competitive, and, in some cases, superior, energy and cooling capacity performance. They are lighter and smaller than conventional mobile air conditioning compressors. Further, these machines operate quietly and exhibit virtually no vibration. Components for 65 of DynEco's latest generation mobile air conditioning Orbital Vane^{tm} compressors have been completed. All machines will be subjected to bench and road testing.

Production cost estimates indicate that Orbital Vane^{tm} compressors will cost about 30% less than standard swash- or wobble-plate compressors to manufacture and on the order of half that of scroll compressors. Several prototype DynEco machines have operated successfully for more than 2500 bench test hours with virtually no wear or decrease in performance.

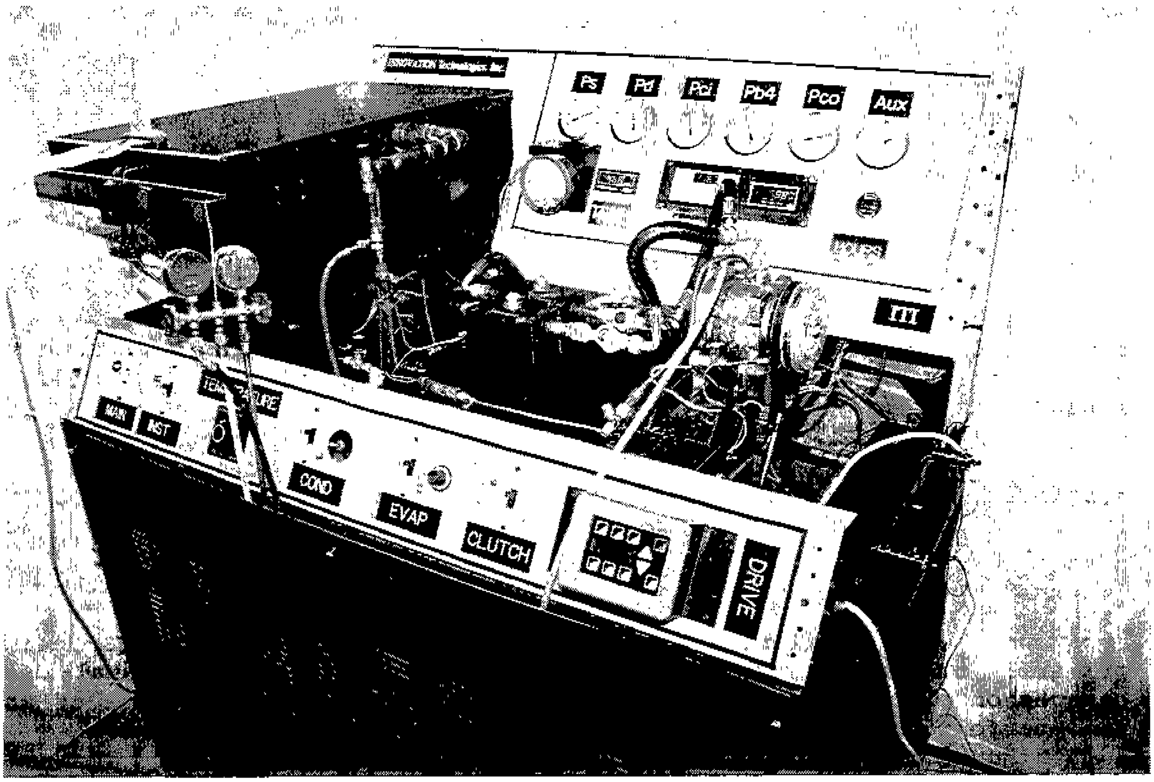

Figure 3: Model 409D2 Mobile Air Conditioning Compressor Under Bench Test

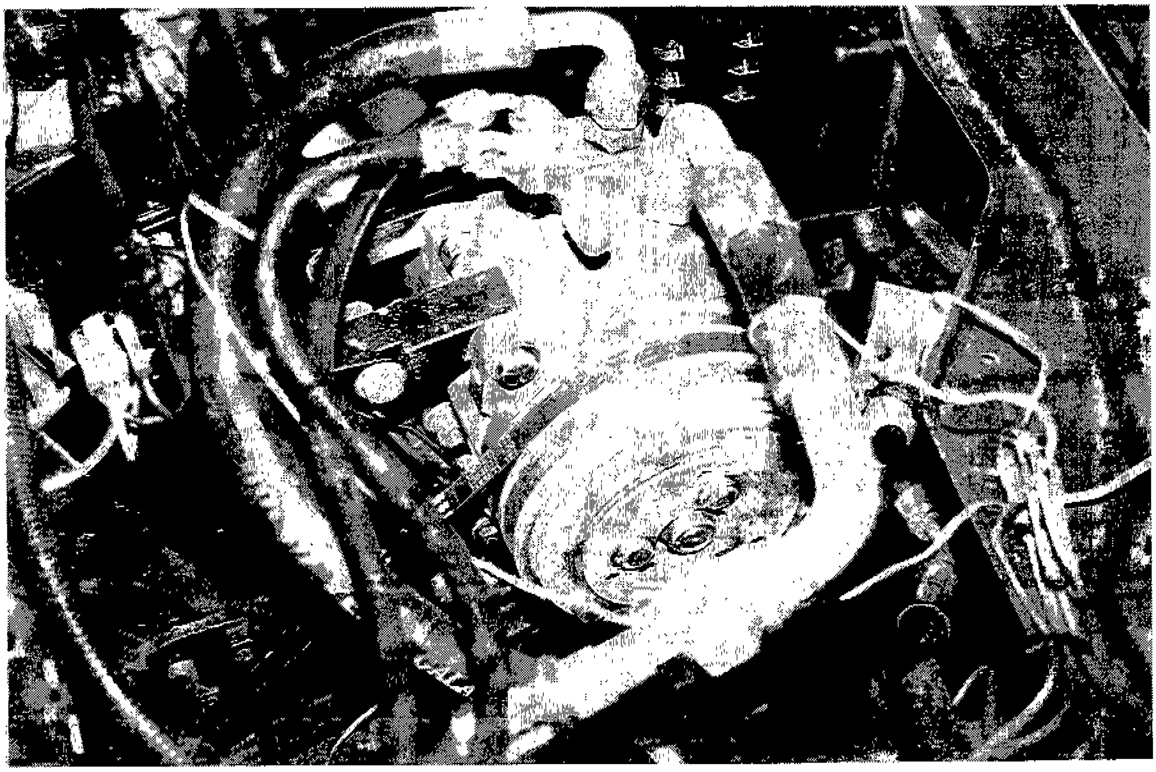

Figure 4: Model 409D2 Mobile A/C Compressor Installed in a 1987 "K" Car